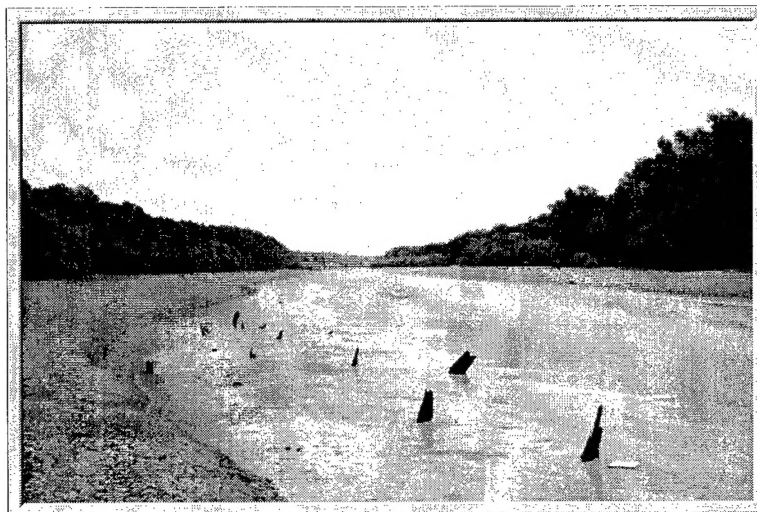




Quantifying Habitat Benefits of Restored Backwaters

PURPOSE: Benefits of restoring riverine backwaters using weirs or other types of water control structures are evaluated. This approach allows: (a) site-specific characterization of backwater fish assemblages; (b) development of quantitative models of habitat quality; and (c) incremental estimation of habitat benefits of weirs with different crest heights. The technique is described within the context of two case histories for backwaters in the lower Mississippi River Basin based on empirical relationships between fish and habitat variables.



Dewatering of backwaters during low river stages can be prevented by installing weirs at the outlet channel

BACKGROUND: Seasonally inundated backwaters are inhabited by numerous fish species of diverse form and biology. Backwaters are particularly important as spawning and rearing grounds for fishes. However, premature or excessive dewatering of backwaters can occur as a result of channelization, channel incision, or water diversion. Low water limits availability of spawning and rearing areas in the littoral zone, contributes to hypoxia and high temperatures in isolated pools, concentrates fishes, and may result in fish kills. Pooling water, however, increases extent and duration of lake margins, allows structurally complex microhabitats to form, and increases the area of open water, enhancing reproduction of fish and other aquatic organisms.

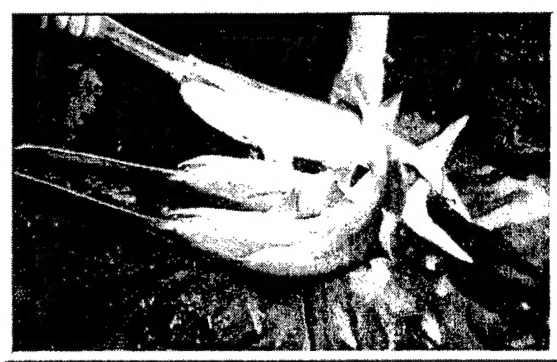
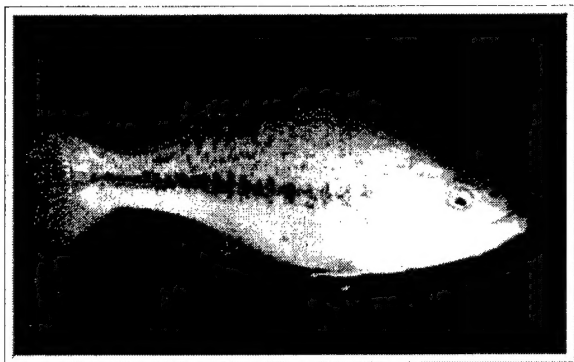
Fixed-crest weirs, installed at the outlets of impacted backwaters, offer a low-cost (i.e., usually less than \$100,000 for construction) means of aquatic restoration, but no technique has been established for quantifying fishery benefits of such structures. Aquatic habitats increase in acreage with weir elevation, but so do construction costs, and habitat quality may vary in noncontinuous patterns. To maximize benefits per cost, it is necessary to develop quantitative models that relate fish habitat to predictable hydrologic conditions (e.g., water depth, river stage) created by the weir.

SAMPLING YOUNG-OF-YEAR FISHES AND THEIR HABITAT: Early life stages of fish are vulnerable to backwater degradation because they have limited motility to avoid predators and declining water quality during low water conditions. Year-class strength of fishes is usually established before the end of a cohort's first growing season; thus, high mortality of eggs and larvae may result in a subsequent decrease in adult recruitment (Diana 1995). For these reasons, backwater

restoration should greatly benefit larval and recently spawned juvenile fishes (collectively referred to as young-of-year).

Backwater drying is problematic, especially for those fishes of the lower Mississippi River basin that continue to spawn and rear throughout summer and even into early autumn, a time when water levels are typically low. Three groups of fish often predominate in backwaters and they represent a comprehensive subset of the biological (e.g., different reproductive strategies) and socioeconomic characteristics of backwater fish communities (Hoover and Killgore 1998a): sunfishes, suckers, and silversides. Sunfishes (Centrarchidae: *Lepomis* spp. [true sunfishes or brim] and *Pomoxis* spp. [crappies]) are usually permanent residents of backwaters that excavate and defend nests throughout the littoral zone, and rear in shallow areas during spring and summer. Suckers (Catostomidae: *Ictiobus* spp. [buffalo] and other taxa) are main channel species that ascend backwaters to randomly broadcast their demersal, adhesive eggs in temporarily flooded littoral zones during spring. Juvenile and adult silversides (Atherinidae: *Menidia beryllina*, *Labidesthes sicculus*) transfer energy from lower levels of aquatic food webs (i.e., zooplankton) to higher levels (i.e., piscivorous fishes) by serving as the principal forage for black basses and other predators. Benefits of backwater restoration are generally evaluated with one or more of these groups.

Nonempirical applications of habitat-evaluation techniques that rely on presumed fish-habitat relationships may not be applicable in a given ecosystem. Thus, we sample young-of-year fishes with floating Plexiglas light traps (Killgore and Morgan 1994) and use these data to develop quantitative models of fish-habitat relationships. Overnight sets of traps are stratified among all apparent macrohabitats and baited with yellow chemical light sticks. This gear-type and method of deployment are known to collect most taxa of fishes in numbers proportional to their abundance among water bodies and among habitat types within individual water bodies. Traps were recovered the following morning and fishes were preserved. Prior to recovery, water depth and distance from shore were measured at each trap. At each location, channel width was recorded and water depth was measured along a horizontal transect. Turbidity, water temperature, conductivity, pH, and dissolved oxygen were also recorded.



Largemouth bass (left) and paddlefish (right) are two of many species that benefit from backwater restoration

CONCEPTUAL FRAMEWORK FOR MODEL DEVELOPMENT: Benefits are calculated using the Habitat Evaluation Procedure (HEP), which expresses habitat quantity as habitat area weighted by habitat quality (U.S. Fish and Wildlife Service (USFWS) 1980):

$$\text{Habitat Units} = \text{Habitat Area} \times \text{Habitat Suitability Index}$$

Empirical (curvilinear) relationships between fish abundance and physical habitat may be used to objectively identify significant habitat variables and quantify habitat value or suitability (HSI). This approach requires three assumptions:

- Young-of-year fish abundance is a positive, direct expression of habitat quality.
- Relevant habitat variables, and ranges for those variables, are included in the analysis.
- Statistical correlation based on empirical data indicate causal relationships between habitat variables and young-of-year fish abundance.

Cumulatively, these assumptions indicate that spawning success (chronology and number of young) may be modified and enhanced by altering the hydrologic regime of backwaters. They also indicate that fish respond to hydrology at varying scales: microhabitat (e.g., point measurements of depth), macrohabitat (e.g., channel width), or ecosystem (e.g., river stage).

Relevant habitat variables are identified with Pearson product moment correlation coefficients and multiple regression analysis (SAS Institute 1989). These techniques provide quantitative models of the relationship between one or more independent (habitat) variables and a single dependent (fish abundance) variable. Regression models are expressed generically as:

$$\text{Fish abundance} = b + m_1\text{Habitat Correlate}_1 + m_2\text{Habitat Correlate}_2\ldots\text{etc.}$$

in which habitat correlates are parameters significantly correlated with fish abundance, and b (y-intercept) and m (slope) are constants. The model allows abundance of fish (number/light-trap) to be predicted for specific values of habitat variables. Regression equations were used as a formula to calculate HSI's by dividing a maximum value into the predicted value of the dependent variable: i.e., number of fish calculated for given value(s) of primary habitat correlate(s).

$$\text{HSI} = \frac{b + m_1\text{Habitat Correlate}_1 + m_2\text{Habitat Correlate}_2\ldots\text{etc.}}{\text{Maximum fish abundance}}$$

The above equation standardizes calculated values of fish abundance to a scale ranging from 0.00 (no habitat value) to 1.00 (maximum habitat value). Maximum fish abundance may be either an observed value (i.e., highest value recorded for that study or in a similar study) or may be a predicted value (based on extreme values observed for hydrologic variables). HSI is multiplied times area of water to obtain a weighted measure of functional habitat area, or Habitat Units (HU's). Calculations are incremental, with increments corresponding to specific elevations planned for different weir alternatives.

Multiple regression equations function similarly to HSI "blue book" equations, by providing measures of habitat quality based on multiple habitat variables. Multiple regression equations,

however, offer several refinements, because they are empirical and do not entail a priori decisions regarding relationships between habitat parameters and fishes, thus reducing institutional bias. Multiple regression statistics allow the elimination of irrelevant variables from the final predictive model and quantification of the degree of correlation between habitat variables and the fish community (via correlation coefficients and probability levels).

RESTORATION OF LAKE WHITTINGTON – A MISSISSIPPI RIVER OXBOW LAKE

Background. Lake Whittington is an oxbow lake of the Mississippi River near River km 926. It was formed in 1937 by the U.S. Army Corps of Engineers after completion of Caulk Island Cutoff. The lake is relatively deep at some locations (greater than 20 ft) and has been commercially and recreationally fished for more than 50 years. It now experiences declining fisheries, presumably because of progressive seasonal dewatering that reduces availability of spawning area in littoral zones and concentrates fish, thereby increasing predation. During high and intermediate stages on the Mississippi River, the surface elevation of Lake Whittington is controlled by the Mississippi River via an inlet/outlet channel and can exceed 30 ft in depth. Bank-full surface area of the lake is 3,000 acres. The bottom of the inlet/outlet channel and natural obstructions in the lake control its surface elevation during low stages of the Mississippi River. During low stages, the lake is dewatered, isolated from the river, and dries partially to form three separate pools consisting of approximately 1,000 acres. The lake typically dewateres during late summer and may remain in this condition through late autumn.

Lake Whittington was compared to two nearby oxbow lakes of the Mississippi delta, north of Greenville, MS (Hoover, Killgore, and Walker 1998): Lakes Beulah and Bolivar. A weir was constructed at the outlet of Lake Beulah in 1955, thus representing a restored backwater. Lakes Whittington and Beulah occur on the Mississippi River floodplain, riverward of mainline levees, and are flooded seasonally (Jan-Apr). Conversely, Lake Bolivar is permanently isolated from the Mississippi River by a mainline levee constructed in the 1930's and is shallow (less than 6 ft). Each lake was sampled once during late spring-early summer.

Habitat Suitability Index Model. Preliminary models for sunfishes and silversides, developed by multiple regression, indicated mean depth as the primary (negative) correlate and turbidity as the secondary (positive) correlate. Abundance of both groups was highest at some intermediate depth: 4 ft for sunfish, 20 ft for silversides. Consequently, regressions were recalculated so that depths corresponding to modal fish abundance were used as a starting point for two separate models for each species: a positive regression from a minimum depth to depth of modal abundance, and a negative regression from depth of modal abundance to maximum depth of occurrence (Figure 1). Minimum depths were approximately 2 and 4 ft for sunfish and silversides, respectively, either because no individuals were collected in shallow water or abundance was extremely low. Thus, we assumed an HSI of 0.00 for depths less than the minimum values. Since turbidity was not expected to change as a result of the project, "second-generation" models did not include that variable.

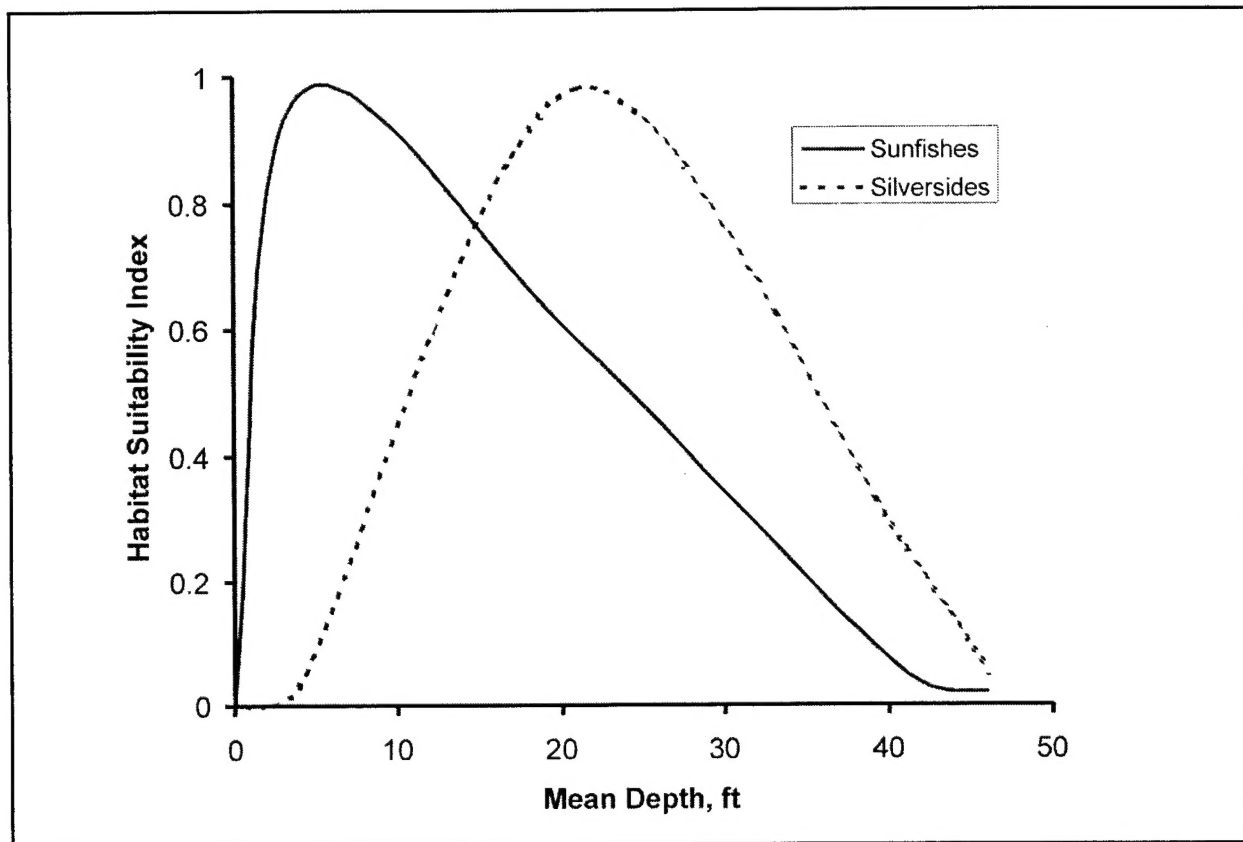


Figure 1. Habitat suitability index curves for young-of-year fishes in Lake Whittington, MS-AR. Equations to describe these relationships can be developed using two separate linear regression models for each species, as described in the text, or curvilinear functions (e.g., polynomial, exponential)

Linear regressions were standardized by dividing by maximum predicted fish abundance:

$$HSI_{\text{Sunfish} > 4 \text{ feet}} = \frac{21.699 - 0.516 (\text{Mean depth})}{19.6}$$

$$HSI_{\text{Sunfish } 2-4 \text{ feet}} = \frac{-31.608 + 14.528 (\text{Mean depth})}{26.5}$$

$$HSI_{\text{Silversides} > 20 \text{ feet}} = \frac{122.724 - 2.467 (\text{Mean depth})}{73.4}$$

$$HSI_{\text{Silversides } 4-20 \text{ feet}} = \frac{-29.25 + 7.312 (\text{Mean depth})}{117.0}$$

Habitat Benefits. The existing 1,000-acre pool has a weighted average water depth of approximately 6 ft. Lowest weir elevation evaluated will create a permanent pool of 2,380 acres with a weighted average water depth of 9 ft; the highest weir elevation evaluated will maintain a minimum

of 2,990 acres and weighted average water depth of approximately 15 ft. Shallow water, 3-9 ft, predominates under existing conditions, so sunfish habitat is relatively high (568 HU's) compared with that of silversides (160 HU's). At the lowest weir elevation, substantial increases in shallow and moderate depths, 12-24 ft, occur and there are correspondingly substantial increases in habitat of both species. With successively increasing weir elevations, however, shallow water persists or increases slightly but moderately deep water increases linearly. As a result, sunfish habitat asymptotes at an intermediate weir elevation and silverside habitat increases linearly. Average gains (between the two taxa) show that for weir elevations greater than 112.5 ft, incremental gains in average HU's decrease from 72 to 29 percent (Figure 2).

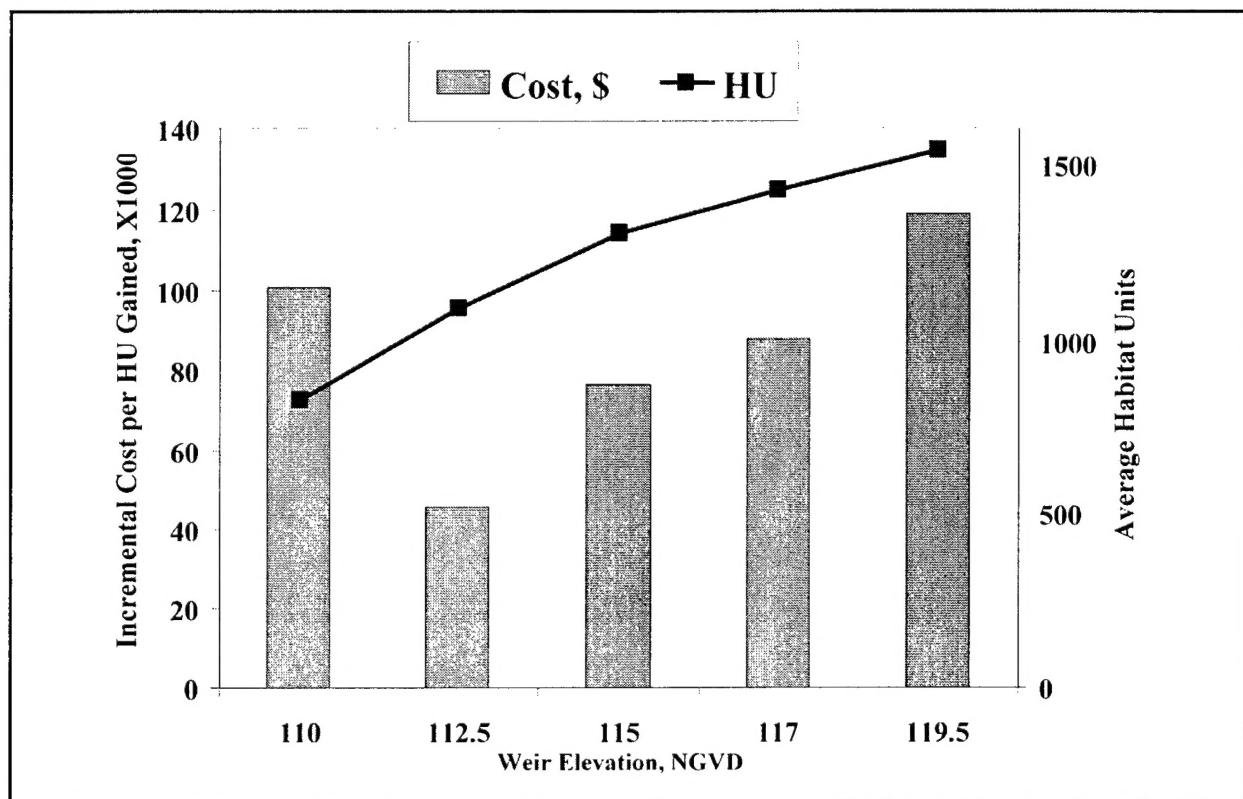


Figure 2. Cost benefit analysis for a fixed crest weir at Lake Whittington, MS-AR: incremental difference in cost per incremental difference in habitat units gained

Cost-Benefits and Weir Height. Estimated average annual cost of weirs, based on a 50-year life of project, ranged from \$84,000 (110.0-ft elevation) to \$ 136,000 (119.5-ft elevation) (U.S. Army Corps of Engineers (USACE) 1996). For each alternative, incremental costs (i.e., cost for a given alternative - cost for the next lowest alternative) were divided by the incremental gain of average sunfish-silverside HU (i.e., gained HU's for a given alternative - gained HU's for the next lowest alternative). This resulted in incremental average cost per HU gained (Figure 2). Cost was lower (\$45.45/HU) for a weir elevation of 112.5 ft than for all other alternatives (\$76.56 to \$119.27/HU). The 112.5-ft weir elevation was selected by the Vicksburg District as the most cost-effective alternative.

RESTORATION OF LAKE GEORGE – A MISSISSIPPI DELTA BACKWATER

Background. Lake George, and its principal tributary, Panther Creek, constitute an extensive backwater of the lower Big Sunflower River in the Mississippi Delta. This backwater system floods annually, during spring, when river elevations may exceed 85 ft National Geodetic Vertical Datum (NGVD). During this period mid-channel depths are 15-20 ft, and channel widths exceed 500 ft. Low water in the Big Sunflower River occurs at some time during the period June through November. River elevations may be less than 70.0 ft NGVD, which is the elevation of lake bottom at its inlet/outlet. As a result, the lake becomes dewatered. During this period, depths in the backwater may be less than 1 ft, with channel widths less than 50 ft. When dewatering is pronounced or prolonged, the upper reach of Lake George dries or is reduced to a series of small, stagnant, isolated pools.

Habitat Suitability Index Model. The lake was sampled five times during spring and summer. Fish habitat was analyzed with a subset of fish community data. Shads, common carp, and western mosquitofish were excluded from analysis. These species predominate numerically in backwater systems and reservoirs but are ubiquitous, invasive, habitat generalists, and as such do not represent the environmental requirements of indigenous, obligate wetland species (Hoover and Killgore 1998a). Consequently, the response variable was total number of larvae and young-of-year juveniles exclusive of these fishes. Remaining fishes consisted of 10 taxa, 90 percent of which were comprised of 3 taxa: buffalo, black and white crappie, and *Lepomis* sunfishes. For correlative analyses, fish and physical habitat data were log-transformed.

Traditional least squares regression models were not statistically significant or highly correlative due to the overwhelming numerical domination by shad and mosquitofish and by exports of late spawners from the backwater during dewatering, both of which obscured fish habitat relationships. However, bivariate plots indicated that there was an increasing number of non-abundant fishes associated with higher river stages (Figure 3). The technique of 90th quantile regressions was recently recommended for “wedge-shaped” data sets of fish standing stocks that depart from patterns of central tendency; i.e., those data sets showing an increasing and increasingly variable fish density along an environmental gradient (Terrell et al. 1996). Thus, the observed 90th quantile value for standardized fish abundance (dependent variable) was determined over the range of river stages (independent variable) sampled. These data, stage and standardized fish abundance at that stage, were used to generate a predictive regression model for interpolating HSI at any river stage from 67- 87 ft NGVD. HSI's represent upper limits on carrying capacity of an organism, or group of organisms; therefore, this technique was adapted as a conservative measure of expressing habitat quality of backwaters as rearing habitat. Standardized fish abundance for HSI model development was calculated as the 90th quantile value of a log-transformed number of fishes for a specific river stage divided by the maximum 90th quantile value of log-transformed number of fishes for any river stage.

Minimal larval densities were observed at river stage 69.6 ft, maximum larval densities at stage 84.8 ft NGVD. Assuming habitat quality asymptotes at higher stages, extrapolated down to an elevation of 67.2 at which HSI = 0.00, a regression model can be calculated based on observed fish abundance at the three lower stages:

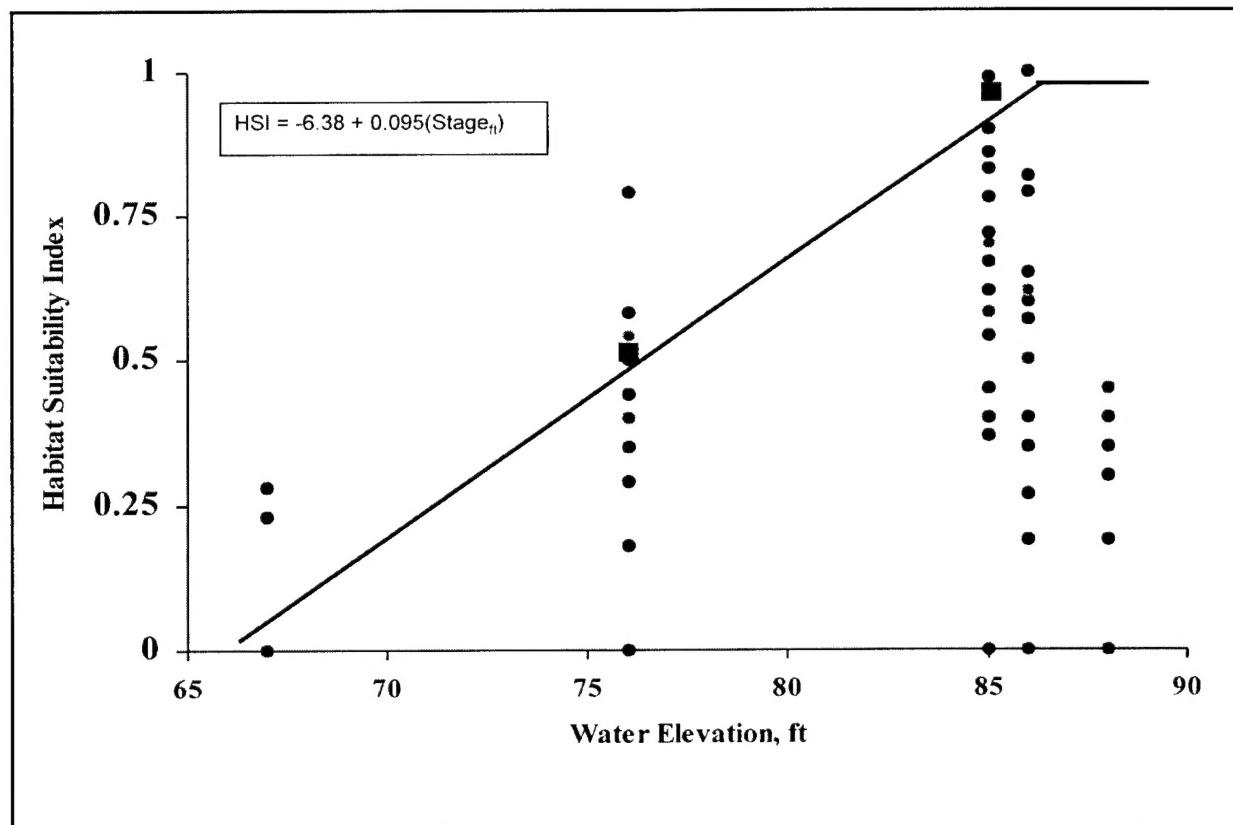


Figure 3. Habitat suitability index model for young-of-year fishes in Lake George, MS. Squares indicate 90-percent quantile and circles are standardized fish abundance of individual collections. Multiple observations of zero abundance not shown

$$HSI = \frac{-6.384 + 0.095(Stage, ft)}{1.748}$$

Statistical significance should not be inferred for a regression calculated from only three points, but the correlation coefficient for this model is high ($r = 0.996$), and predicted values for HSI differ from observed values of standardized fish abundance by less than 0.05. Abundance of fishes in individual light traps at any stage was highly variable, but many approached or exceeded values represented by the model. Consequently, the authors believe that HSI values are conservatively low estimates of habitat value of the Lake George system to recently spawned fishes.

Habitat Benefits. Monthly acres of water, based on river stages ranging from 70-90 ft, were estimated from a stage-area table and HU's calculated for four different weir elevations: 75, 76.5, 78, and 80 ft NGVD. Habitat units increased for all weirs during the low-water period of July-November (Figure 4); the weir with the highest elevation (80 ft) also created habitat outside this period, i.e., December-February (Hoover and Killgore 1998b). Habitat gains for the entire ecosystem, per month, during this time were relatively small (0-60 percent for the entire system) compared with those during the critical low-water period (202-845 percent) reflecting lower likelihood of fish spawning during the winter months.

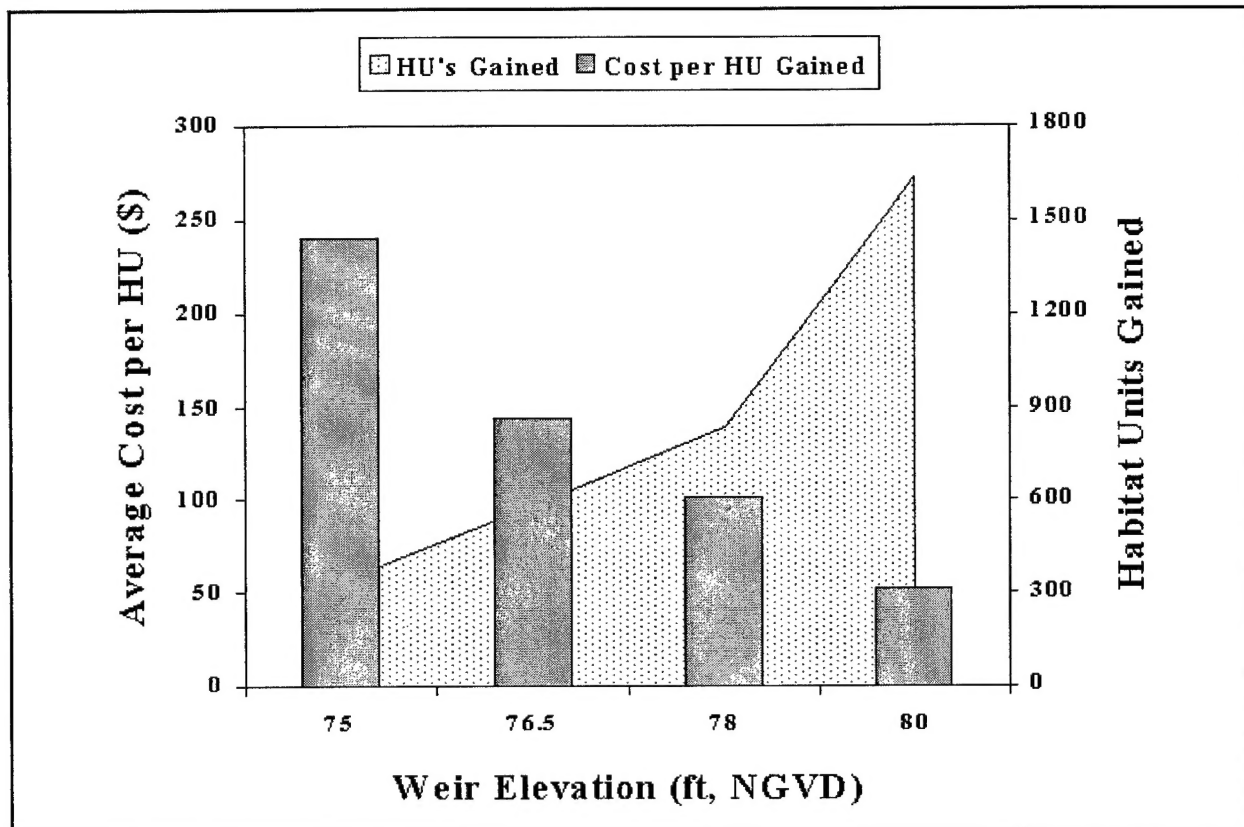


Figure 4. Cost benefit analysis for a fixed crest weir at Lake George, MS: incremental cost per habitat unit gained

Cost Benefits and Weir Height. Estimated annual cost of weirs, based on a 50-year life of project, ranged from \$81,000 (75-ft elevation) to \$86,000 (80-ft elevation) (USACE 1999). For each alternative, total cost was divided by gained HU's. This resulted in cost per HU gained for each alternative (Figure 4). Cost was lower (\$53/HU) for a weir elevation of 80 ft than for any other alternative (\$102-240/HU). The 80-ft weir elevation was selected by the Vicksburg District as the most cost-effective measure.

SUMMARY: Backwaters are important nurseries for riverine fishes, but simple, empirical techniques for quantifying their value prior to and following habitat restoration have not been established. Plexiglas light-traps effectively sample young-of-year fish assemblages in specific habitats of backwaters and can, therefore, be used to provide data for a wide variety of sampling regimes. Case histories are presented from the lower Mississippi River Basin demonstrating that light traps may be deployed once, over an extensive range of habitats, or repeatedly within a narrower range of habitats, to provide data that adequately describe relationships between hydrologic conditions (habitat or stage) and fish abundance. Statistical models are readily developed between river stage, or individual habitat parameters, and fishery response variables. These models are easily modified for use in traditional habitat assessment techniques, such as Habitat Evaluation Procedure (HEP) and cost-benefit analyses. Unlike "off-the-shelf" habitat models, they represent fish assemblages and physical habitat conditions distinctive to individual water bodies.

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www.wes.army.mil/el/emrrp

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